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NEW TECHNIQUES FOR PROCESSING OF MUNICIPAL REFUSE

Torsten Rothman, P. E.
Major USAF, BSC

TECHNICAL REPORT NO. AFWL-TR-71-41

April 1971

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base
New Mexico

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FOREWORD

This research was performed under Program Element 63723F, Project 683MII.

Inclusive dates of research were 1 July 1970 through 1 February 1971. The report was submitted by the Air Force Weapons Laboratory Project Officer, Major Torsten Rothman (DEZ-E).

I would like to acknowledge the assistance in reviewing this report and the thoughtful and pertinent comments of Dr. Boyd T. Riley and Mr. Troy Marceleno of the Solid Waste Management Office, Environmental Protection Agency, Cincinnati, Ohio, and Major James T. Wallace of the USAF Regional Environmental Health Laboratory, McClellan AFB, California.

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ABSTRACT

(Distribution Limitation Statement No. 3)

New methods were investigated for processing and disposal of municipal refuse. Volume reduction techniques including incineration and several variations, pyrolysis, compaction, and grinding are discussed in detail. Resource recovery and storage, collection and transportation are also covered. New equipment for sanitary landfill operation and selected cost data conclude the report.

CONTENTS

ILLUSTRATIONS

TABLES

SECTION I

INTRODUCTION

The newer methods of volume reduction and processing of solid wastes, particularly municipal refuse, are discussed. Some of the disposal methods now in use, such as open dumping, with or without burning, contribute to air pollution, serve as breeding grounds for disease vectors, and are aesthetically unacceptable. Sanitary landfilling without prior volume reduction results in unnecessarily rapid depletion of available land. This can prove to be a severe problem in those areas where land is at a premium. Other facets of solid waste management including storage, collection, and transportation and resource recovery by recycling, will also be considered. It is in the first two areas where most of the problems occur and where the majority of the research is directed and new developments achieved.

A review of the current Air Force publications on this subject (AFR 91-11, AFM 85-11, and AFM 88-11) reveals incineration as the only volume reduction technique mentioned, and sanitary landfill as the ultimate disposal method. The incinerator design that is illustrated and discussed is a batch fed, manually stoked, stationary grate type (ref. 1, 2). In the past few years there have been many improvements in incinerator design and operation as well as development of other volume reduction techniques.

It is anticipated that this report will serve civil and bioenvironmental engineers as a convenient source of information for guidance in the selection of refuse processing and disposal methods. Additional information is available from the equipment manufacturers and the Air Force Weapons Laboratory.

There are two prime criteria in the evaluation of any refuse processing and disposal method. First, it must not degrade the environment. As a Federal agency the Air Force must, by Executive Order, provide a leadership role in "protecting and enhancing the quality of the Nation's environment" (ref. 3). Improper handling or disposal of municipal refuse can result in pollution of the air and the water. It is essential that adequate pollution control technology be applied to whatever refuse processing and disposal method is selected. The second criterion is cost. Several commercial concerns are trying to develop techniques to make the treatment and disposal of municipal refuse a profit making operation. Recovery

of valuable items by sorting and separating or production of useful by-products by combustion or pyrolysis are potential sources of income. With the present state of technology and economic situation, no method of refuse disposal is self-supporting, and a charge must still be paid by the generating agency. However, the proposed Hercules plant in New Castle County, Delaware, incorporating metal recovery, composting, and pyrolysis is designed to be self-supporting (ref. 4). The refuse processing system proposed by Black Clawson Company is also designed to pay for itself. The system uses a Hydrapulper wherein all grindable materials are pulverized and put into a slurry system. Recovery of paper fiber, ferrous metals, glass cullet, and aluminum is claimed to provide an income roughly three times the operating cost (ref. 5).

Municipal refuse volume reduction methods to be covered in this report include incineration, pyrolysis, compaction, and grinding.

Sorting, separating, and composting, as well as other resource recovery schemes, will be discussed. The emphasis in federally supported research programs is now directed toward recycling of materials (ref. 6).

The design and operation of a sanitary landfill is adequately covered in existing Air Force publications (refs. 1, 2), and, therefore, is not included in this report. Recent developments in sanitary landfill equipment will be briefly discussed.

The various processing and disposal methods will be compared as to initial capital investment and operating costs where such information is available.

Finally, a brief discussion of the storage, collection, and transportation of municipal refuse will conclude this report.

It should be emphasized that several of the volume reduction methods included in this report are not economically feasible for the relatively small amount of refuse generated by an Air Force base. They are included in the report so that possible Air Force participation in regional solid waste management systems can be evaluated with some knowledge of the treatment system proposed.

It should also be noted that no single technique is applicable in all cases. Geographical, climatological, economical, and other differences of locale as well as waste characteristics require individual evaluation of each situation.

The mention of specific products and/or systems by name is for identification only and does not constitute endorsement by DOD, USAF or the author.

SECTION II

VOLUME REDUCTION

This section includes incineration with various modifications, some of which are presently operational and some of which are under development. Also covered are pyrolysis, compaction, and pulverization (size reduction) of municipal refuse. It should be emphasized that these are not disposal methods, they only reduce the amount that requires ultimate disposal, thus reducing transportation costs and conserving landfill space. This report is not meant to be an exhaustive dissertation on each system or method presented. Rather it is intended to give the reader an introduction to the various processes and a grasp of the fundamentals involved. More detailed information is available in the references quoted.

1. INCINERATION - GENERAL

Incineration is "a controlled combustion process for burning solid, liquid, or gaseous combustible wastes to gases and to a residue containing little or no combustible material" (ref. 7).

An incinerator is an industrial processing plant (ref. 8) of which the furnace, where the actual combustion takes place, is the most important part (fig. 1). Other segments of the plant are the weighing station, receiving area, storage pit, charging system, air supply, quench tank, air pollution control device, and stack.

In the past, construction and operating costs of incinerators have limited their application to areas with large populations. Recent developments have shown certain types to be economical for relatively small populations of around 12,500, which is comparable to an average Air Force base (refs. 9, 10).

Early incinerators, some of which are still in operation, were batch fed, manually stoked, had fixed grates, and virtually no control over the quantity or distribution of the combustion air. They were a source of air pollution, mainly particulates and odors, a hazard to the operators, and in many cases only warmed the refuse with little or no volume reduction.

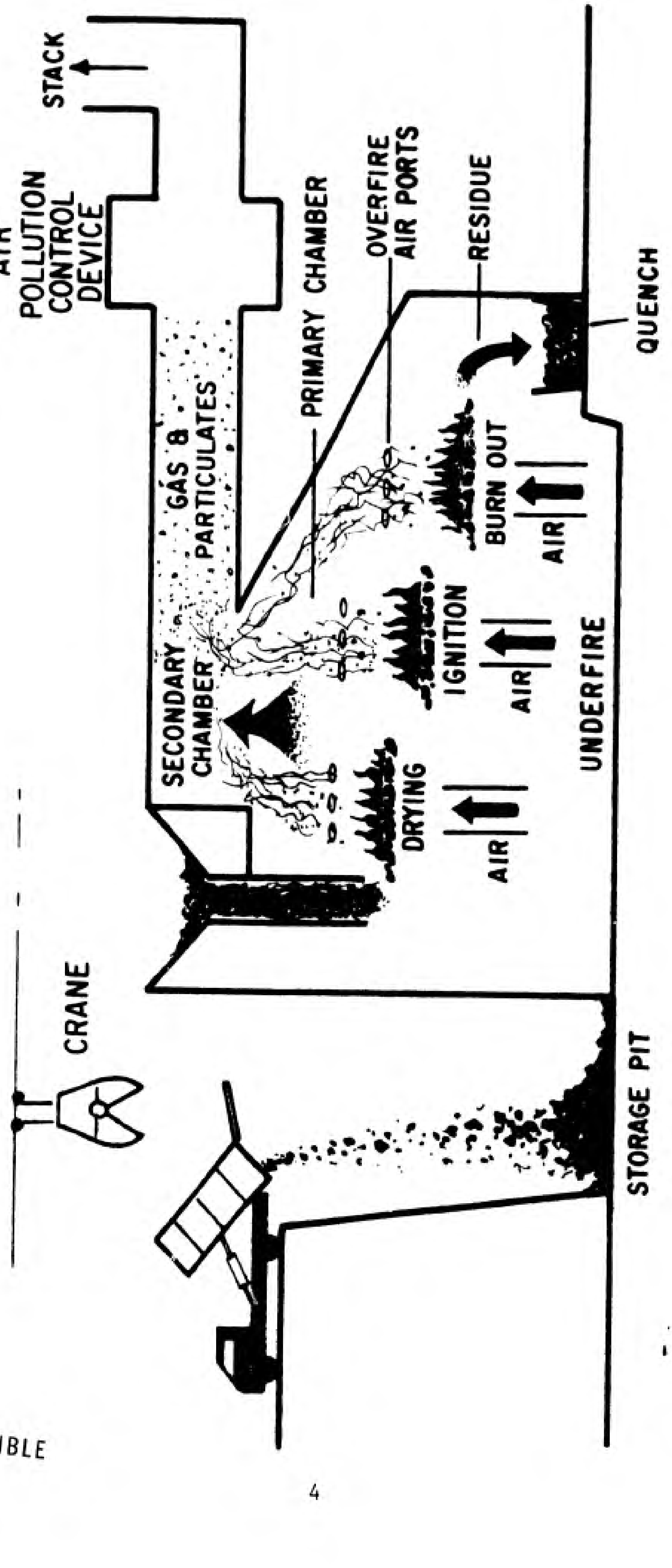

Figure 1. Incineration

Modern municipal incinerators normally have continuous feed, mechanical stoking by a variety of techniques, most of which employ grate motion of some sort, and the over- and underfire combustion air distribution is controlled, sometimes automatically.

A typical well designed furnace will be fed through a chute that is kept full of refuse to serve as an air lock. The wastes drop onto a drying grate where the water is evaporated and the temperature increased. The dried waste is moved to the ignition grate by rocking, reciprocating, rotating, or forward motion of the grate. From the ignition grate it goes to the burn-out grate from where the noncombustible residue finally drops into a quench tank. Three grate functions have been described. These grate functions could be simply consecutive areas of the same grate where the refuse is moved along mechanically. They could also be physically separated but similar grates, i.e., three endless belts dropping the refuse from one to the other or the Dusseldorf drum grates (ref. 11). They could also be completely different grates, i.e., the Volund system where the drying and ignition takes place on reciprocating grates and the final burn-out in a rotary kiln (ref. 12). Grates shown in figure 1 are symbolic and not intended to represent any one type.

Weighing of incoming refuse and outgoing residue is necessary to determine cost apportionment in cases of more than one user and for calculation of efficiency based on weight.

The receiving area should be covered, provide easy access and egress for vehicles to the tipping floor, and be easily cleaned.

The storage pit should have a capacity of 100 to 150 percent of the daily rated incinerator capacity (ref. 8). It should also have drains and rounded corners for easy cleaning. It must be constructed of durable materials to prevent damage from refuse or crane.

Charging can be performed by pneumatic ram (horizontal feed) or by crane into a vertical hopper. The grapple type bucket was developed specifically for incinerator work and has a higher capacity than other types (ref. 8).

Refractory lined incinerators generally operate with around 150 to 200 percent excess combustion air (ref. 7) (i.e., two and one-half to three times the stoichiometric requirement for complete combustion); some go as high as 500 percent (ref. 8). This large excess of air is necessary to (1) ensure complete combustion, and (2) to keep the temperature in the furnace below approximately

2000°F to limit slag formation (ref. 8). Water wall furnaces generally require less air since some heat is absorbed by the wall and they operate with around 50 to 100 percent excess air (ref. 7). Air is generally introduced below (underfire) and above (overfire) the fuel bed. Increasing underfire air increases the burning rate (ref. 8), but it also increases the generation of particulates. Increasing overfire air gives more complete combustion of the gases and particulates by increasing turbulence and available oxygen, but too much overfire air will cool the gases and result in unburned material leaving the furnace (ref. 8). Most plants operate with 40 to 60 percent of the total air introduced as underfire air (ref. 7).

Water is used to quench the residue coming out at the end of the incinerator. This residue can be removed from the quench tank by an endless belt type system for transportation to the ultimate disposal site. The quench water itself generally requires treatment of some sort prior to release. A recent study yielded the values (table I) for selected parameters (ref. 13).

Table I

INCINERATOR QUENCH WATER CHARACTERISTICS

Parameter	Range
pH	3.9 - 11.5
Suspended Solids	450.0 - 1860.0 mg/1
Dissolved Solids	360.0 - 2660.0 mg/1
Chlorides	98.0 - 680.0 mg/1

The present Federal air pollution standard for particulate emissions from an incinerator burning more than 200 pounds of waste per hour is 0.2 grains per standard cubic foot corrected to 12 percent CO_2 (ref. 14). To meet this standard, very high efficiency air pollution control equipment is required. The cost of this equipment may represent 10 percent or more of the capital cost of the incinerator plant (ref. 7). Electrostatic precipitators are widely used in Europe and have been installed in a few incinerators in the U.S. (ref. 10). High-energy wet scrubbers can also meet the emission standards but tend to give a water vapor plume that may be undesirable (ref. 11). Wet collection systems also pose a problem in the treatment of the scrubber water and the corrosion of the piping

system (ref. 8). Bag filters are not used at present but are proposed for the Torrax high-temperature incinerator (refs. 8, 11, 15, 16) and have been recommended for existing municipal incinerators in New York City (ref. 17).

Incinerator efficiency can be expressed in terms of reduction in weight, volume, volatiles, and the amount of available heat released (ref. 13). Weight and volume reduction are both functions of the character of the incoming waste and thus poor parameters for comparing incinerators. Reduction in volatiles and release of available heat are better indication of the degree of "burn-out" or efficiency of the incinerator (ref. 13).

2. INCINERATOR TYPES

a. Incineration - Rotary Kiln

A rotary kiln incinerator (fig. 2) gives excellent burn-out as a result of the vigorous agitation of the refuse. Another result of this agitation is the considerable entrainment of particulates and consequent increased air pollution potential. It is comparatively expensive to construct. Preassembled or packaged rotary kiln units with capacities of from 76 to 3230 lbs/hr of type 2 waste are available (ref. 18). The Volund type (see earlier discussion) of full scale municipal incinerator is normally not constructed for less than 200 ton/day capacity (ref. 12).

b. Incineration - Starved Air

The starved air incinerator (fig. 3) is so named because it uses less air than normal, refractory lined incinerators.

One design uses a circular cross-section furnace (ref. 19). Another design uses a parabolic arch design (ref. 20). Both introduce air through holes in the lower portion of the wall. The air agitates the refuse that is deposited directly on the floor of the unit and provides the oxygen for combustion. Fuel gas or oil is also introduced during the start-up period to initiate the combustion. The length of time auxiliary fuel is required is dependent upon the type of waste and its moisture content (ref. 21). The smoke that is generated is consumed in a gas-fired afterburner located in the bottom of the stack.

The Consumat and Combustall units meet the federal criteria for particulate emission from incinerators and have been approved for use by federal facilities (refs. 19, 20). Standard units are available with capacities from 50 to

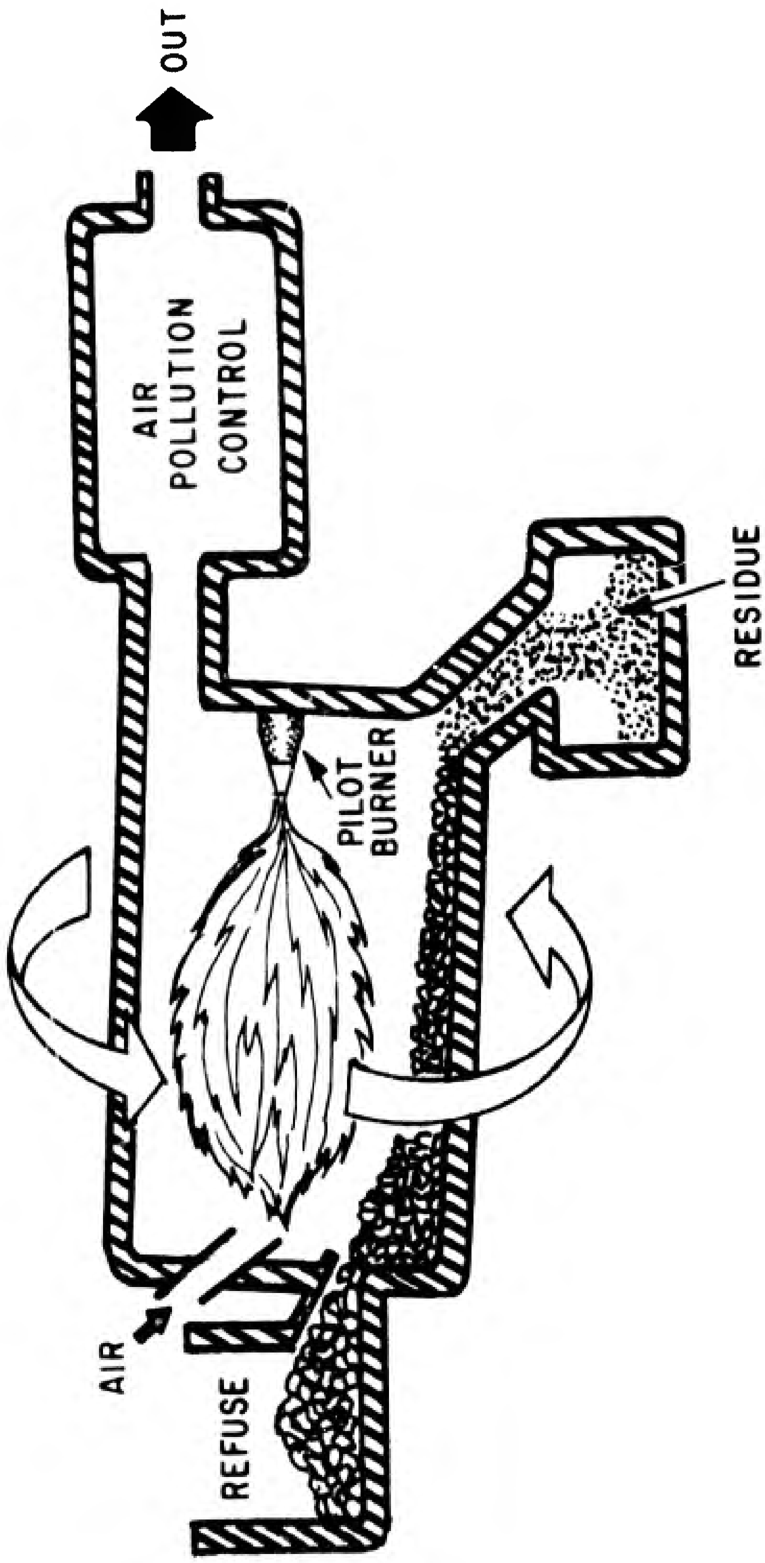

Figure 2. Rotary Kiln Incineration

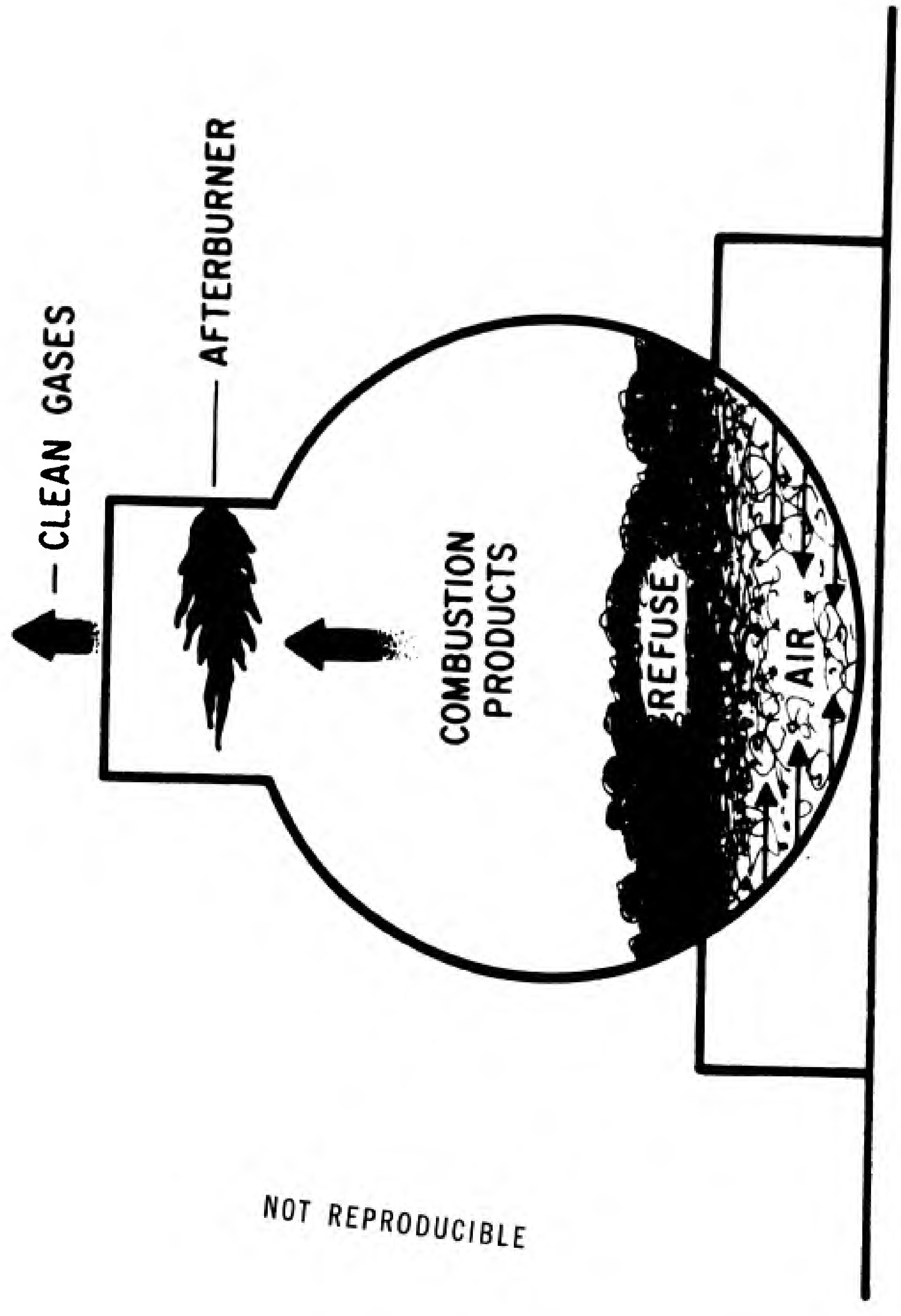

Figure 3. Starved-Air Incineration

3500 lbs/hr (ref. 19) and from 300 to 1750 lbs/hr of type 2 waste (ref. 20). Larger units can be custom built (ref. 19). The unit must be shut down periodically to permit removal of the noncombustible residue.

c. Incineration - Underground

This is a patented process (fig. 4) that is reported to have been successfully field tested and is now undergoing evaluation and refinement (refs. 22, 23).

For the field test, a square cell with 8-foot high walls was built. The walls or berms were constructed of construction rubble with a layer of sand topped by a layer of impermeable clay on the outside wall. The sand and clay act as filter media for the smoke that is generated. The cell was filled with refuse that was covered by a layer of loose clay soil. Ignition was accomplished by lighting charcoal placed in pits on the surface of the cell. An air-supported canvas dome covered the cell. A metal cover is proposed for future operations. Air is blown in under the cover and forced down into the cell to support the combustion. A combustion cycle takes approximately 20 days, and the noncombustible residue makes a stable landfill material.

The process is claimed to emit no smoke, particulates or carbon monoxide. Negligible amount of nitrogen, sulfur oxides, and aldehydes were detected and odors were minimal (ref. 22).

d. Incineration - High Temperature

This process (fig. 5) is also known as "total" or "slagging" incineration (ref. 24). There are several units in various stages of development each differing in certain details; only three will be discussed in this report. All units operate at very high temperatures, around 2600 to 3200°F, and produce a sterile, solidified slag, free of putrescible material (refs. 24, 25). Advantages of this system include (1) a residue that does not require burial (refs. 11, 26), and (2) smaller flue-gas volumes as a result of using less combustion air than conventional incinerators, thus smaller air pollution control equipment is necessary (ref. 24). Disadvantages of this system include (1) a requirement for supplementary heat to maintain the higher temperatures, and (2) an expected substantial increase in nitrogen-oxide formation resulting from the high heat release rate (ref. 24).

The Solid Waste Management Office (ref. 26) is working on a high-temperature (approximately 2600°F) incinerator fed by a shear-edged hydraulic ram. High-velocity air jets that are tangentially introduced supply combustion

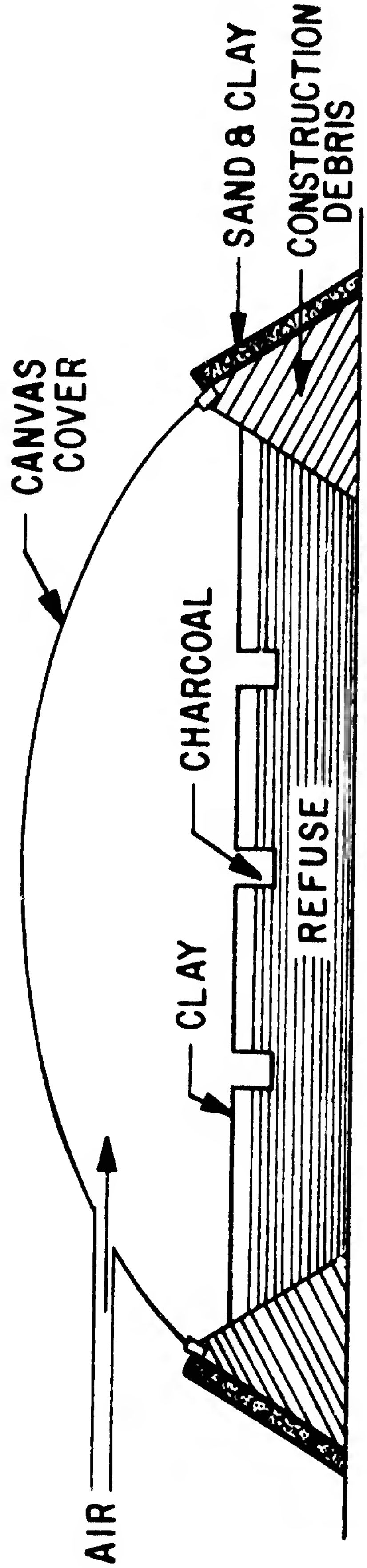

Figure 4. Underground Incineration

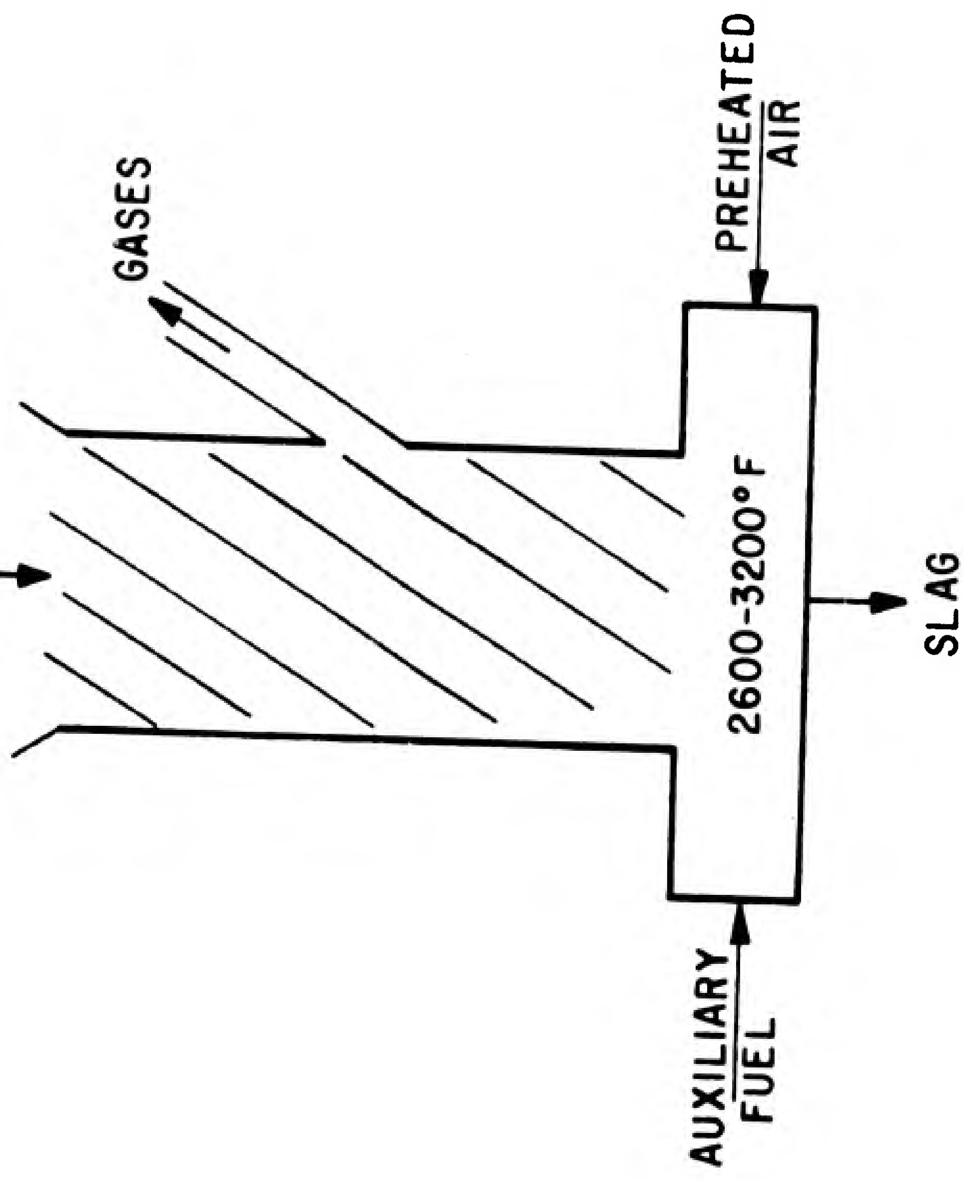

Figure 5. Total Incineration

air and are used for stoking. This unit does not use auxiliary heat; it does preheat the combustion air by heat exchange with the exhaust gases.

The Melt-Zit incinerator (ref. 25) is basically a vertical, cylindrical furnace with the refuse fed in about midway up the stack. A bed of burning coke maintains the temperature from 2600 to 3200°F. The combustible refuse burns in suspension and on the bed while the noncombustibles melt on the bed and are drained from the furnace as molten slag and iron. Excessive particulate emissions require that a secondary combustion chamber be included to further burn the gases and particulates (refs. 25, 27).

The Torrax system (ref. 15) uses combustion air preheated to around 2000°F. The refuse is fed into a vertical cylinder where a counter current flow of hot gases decompose most of the readily combustible materials. The materials reaching the base are either burned in the 2600 to 3000°F environment or liquified. The molten material is quenched in a water tank. The gases and entrained particulates are reacted with air at about 2400°F. The resulting gases are then passed through a heat exchanger and finally through a fabric filter.

e. Incineration - Fluidized Bed

In the fluidized bed incinerator (fig. 6), the refuse to be burned is placed in a bed of granular material that is kept in suspension by a fluidizing gas (ref. 28). There are several advantages to this type of a system: (1) it provides rapid and very complete combustion of the material, (2) it operates with low excess air requirements, perhaps as low as 5 percent if the bed is at ambient pressure, and (3) it operates at lower temperatures with resulting lower production of oxides of nitrogen (ref. 28). Operation at very low excess air inputs is not practical because of the high temperatures and slagging that result; air inputs must also be sufficient to fluidize the bed (ref. 26). Major problems have been encountered in feeding the solid wastes to the fluidized bed incinerator (ref. 28).

In the CPU-400 Combustion Power Unit (fig. 7), which is currently being developed, feeding of refuse into the fluidized bed, which operates at 60 psia pressure, is accomplished by a high-pressure rotary feed valve after size reduction of the refuse and air classification that removes glass and metal (refs. 29, 30). The hot gases leaving the CPU-400 will be cleaned and then expanded through a gas turbine to create about 15,000 kw of electrical power (refs. 11, 29, 30). The waste heat can be used to accomplish one of the following: desalinate 2.5 million gallons/day of water; generate 82,300 lbs/hr of steam; incinerate 79,000

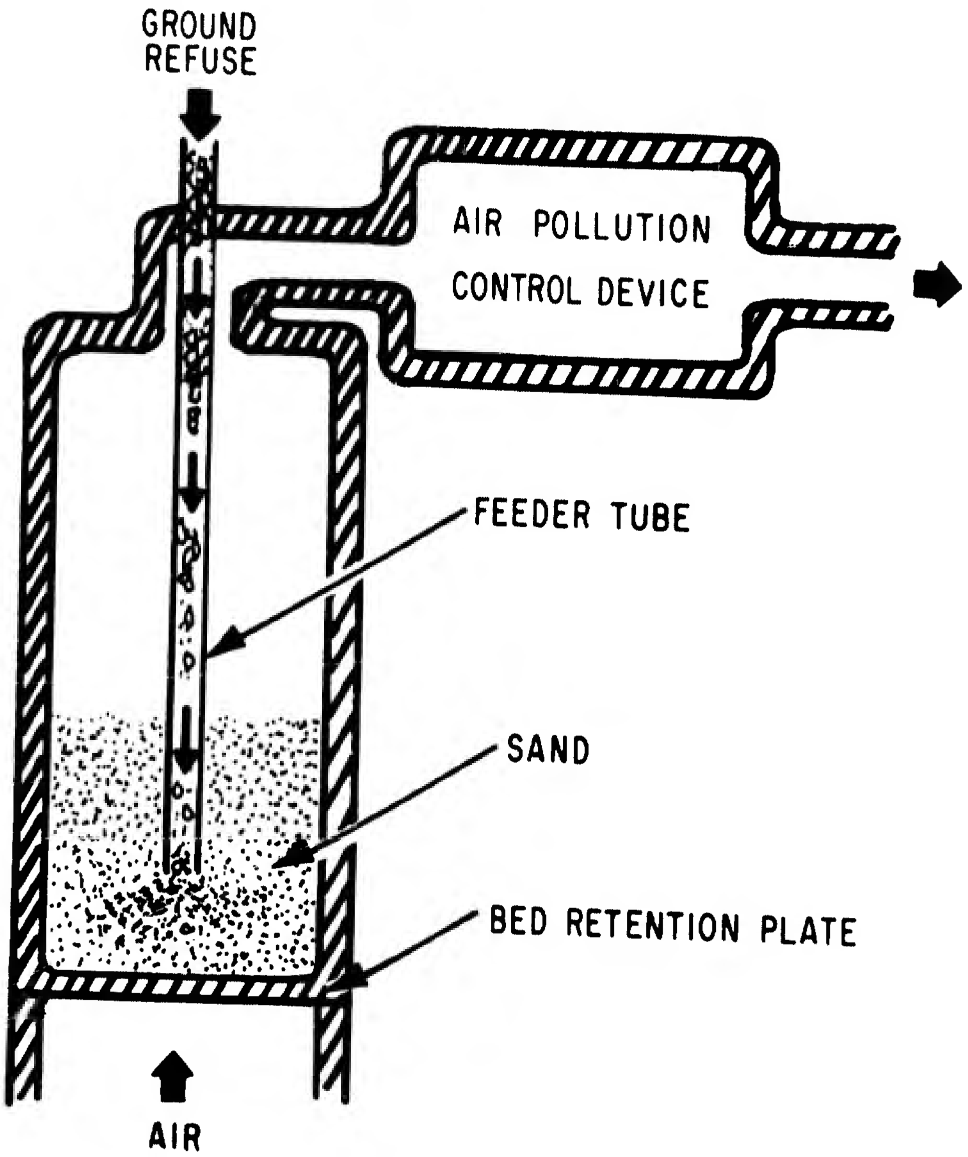

Figure 6. Fluidized Bed Incineration

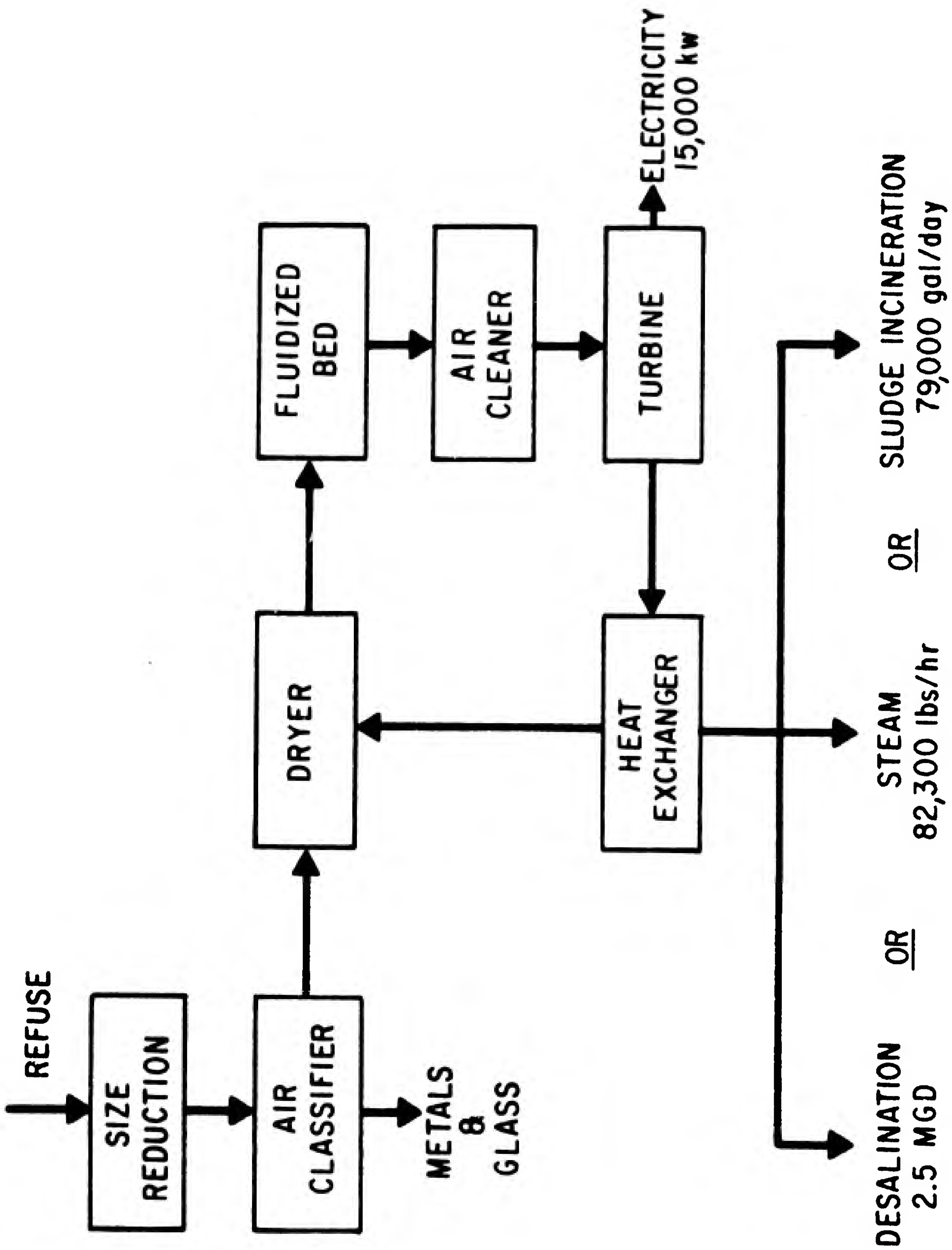

Figure 7. CPU-400

gallons/day of sludge (ref. 31). Maintenance of the high-pressure environment in the bed results in 300 to 400 percent excess air levels in the system (ref. 30). A one-tenth scale pilot plant is scheduled for operation in early 1972, and a full scale prototype is expected to be ready by 1975 (ref. 30).

f. Incineration - Vortex

The General Electric Company has developed a high-temperature vortex incinerator (fig. 8), which is named "Vorcinerator" (ref. 32). The 1-1/2-ton/hr demonstration unit has successfully completed the initial test phase. A 6-ton/hr unit will be built in the future (ref. 33). The Vorcinerator is claimed to have a capacity of 10 to 20 times that of conventional incinerators (ref. 33). The refuse is pulverized and blown into the cylindrical combustion chamber tangentially so that the major part of the burning takes place in suspension (ref. 22). An excellent burn-out is achieved (ref. 22). The gases and particulates are sent through a cyclone scrubber and the particles removed returned to the furnace. A high efficiency air pollution control device is necessary if the incinerator is to meet Federal air pollution criteria.

g. Incineration - Trench

The trench incinerator unit (fig. 9) was developed at E. I. Dupont de Nemours Co. for the thermal destruction of high-heat content, low-ash wastes (ref. 34). In essence, it is a trench with a blower providing a curtain of air across the top at a slight downward angle. The waste is introduced at the bottom and the air curtain provides the oxygen and turbulence necessary for burning. This unit has been evaluated by the National Air Pollution Control Administration for municipal refuse and was found not to meet the federal criteria for particulate emission from incinerators (refs. 14, 34). It was observed that unburned material passed through gaps in the air curtain resulting from the nozzles in the manifold (ref. 26).

h. Incineration - Miscellaneous

There is a study underway in St. Louis to supplement the coal for a power plant with ground refuse; the refuse will provide approximately 10 percent of the BTU input (refs. 10, 27).

Sometime ago it was proposed to convert several moth-balled Liberty ships into floating incinerators. The refuse was to supply the energy to drive the

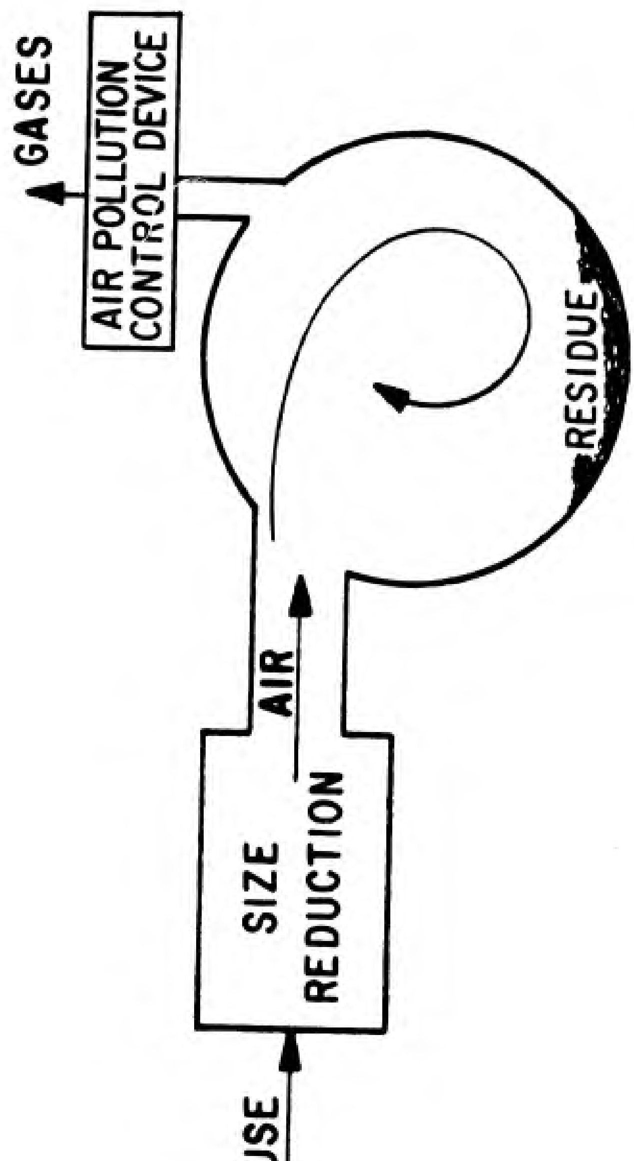

Figure 8. Vortex Incinerator

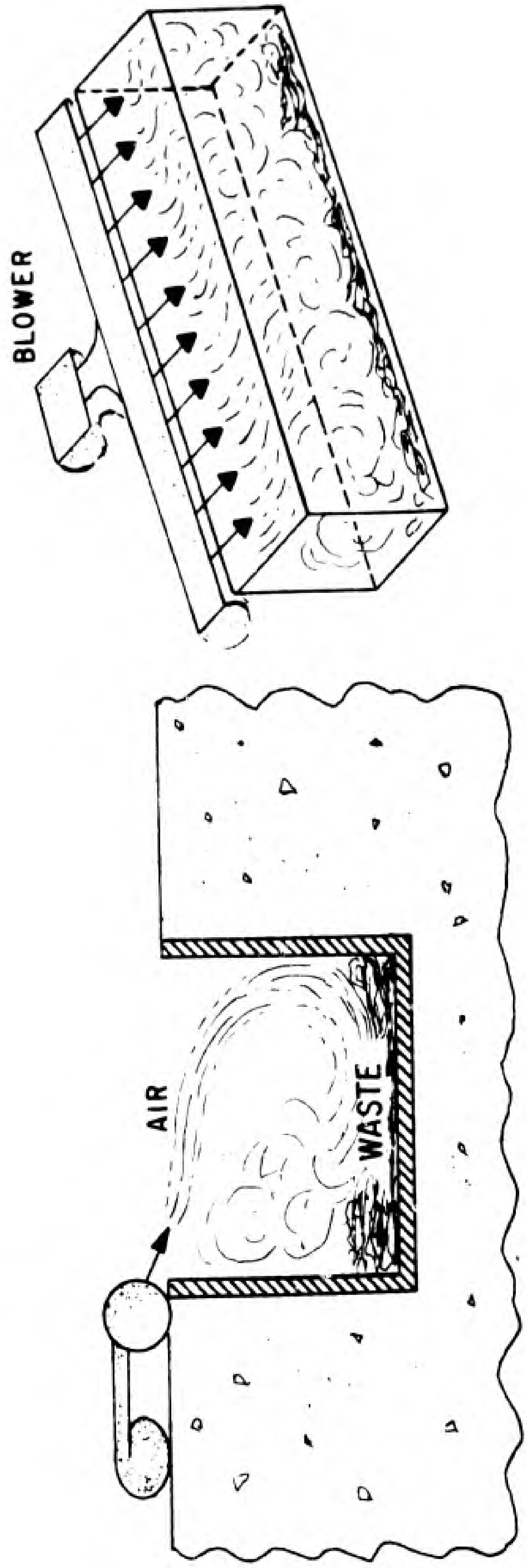

Figure 9. Trench Incinerator

ship while it sailed well away from land. The residue would be dumped overboard before the ship returned for another load (ref. 35). This idea lost popularity for reasons unknown to the author. Its revival seems unlikely in view of current opposition to marine disposal of wastes.

i. Pyrolysis

Pyrolysis (fig. 10) is the process of chemical change by the action of heat in the absence of oxygen (ref. 36). It is also referred to as destructive distillation. Lately pyrolysis as a means of volume reduction of municipal refuse is receiving a great deal of attention. It is an attractive technique because it offers the possibility of financial recovery from sale of gaseous, liquid, and solid fractions generated. It also creates less air pollution since there is no burning, per se, of the refuse. Expenditures for air pollution control equipment are thus greatly reduced. While the proposed systems vary in detail, the general approach is as follows: the refuse is ground and introduced into a vessel that is then sealed off. Heat is then applied and the gases generated are put through a collection system. The process yields water, combustible gases, tarry liquids, and a stable residue (ref. 11). A portion of the generated gas can be burned to provide the heat necessary to maintain the pyrolysis. Studies have shown that there is more than sufficient gas produced for this purpose (refs. 11, 36, 37, 38). Heat values range from 300 to 563 BTU/cubic feet (refs. 36, 37). The tars and other hydrocarbon liquids produced are potential sources of organic compounds such as benzene, toluene, etc. (refs. 36, 37). The solid residue, without metals, glass, etc. that can be separated before or after the pyrolysis, is comparable to coal and can be used as a fuel (refs. 36, 37). Ninety to 95 percent, by volume, of the gases produced by pyrolysis at temperatures ranging from 900 to 1700°F (480 to 930°C) consisted of hydrogen, carbon monoxide, carbon dioxide, and methane (refs. 36, 37).

In the pyrolysis unit developed by Enviro-Chem (ref. 39), a subsidiary of Monsanto Chemical, no attempt is made to recover or use any of the products. After the refuse is pulverized, it is introduced into a rotary kiln by a hydraulic ram feed system. The kiln is heated with an internal flame fed by propane mixed with air in a ratio to provide 90 percent of the stoichiometric oxygen requirement. There is, therefore, no oxygen for the combustion of the refuse that reaches temperatures around 1600 to 1800°F and undergoes pyrolysis. The gases generated are burned with no attempt at heat recovery, and the solid residue drops into a water quench tank to be removed for burial. In tests with municipal

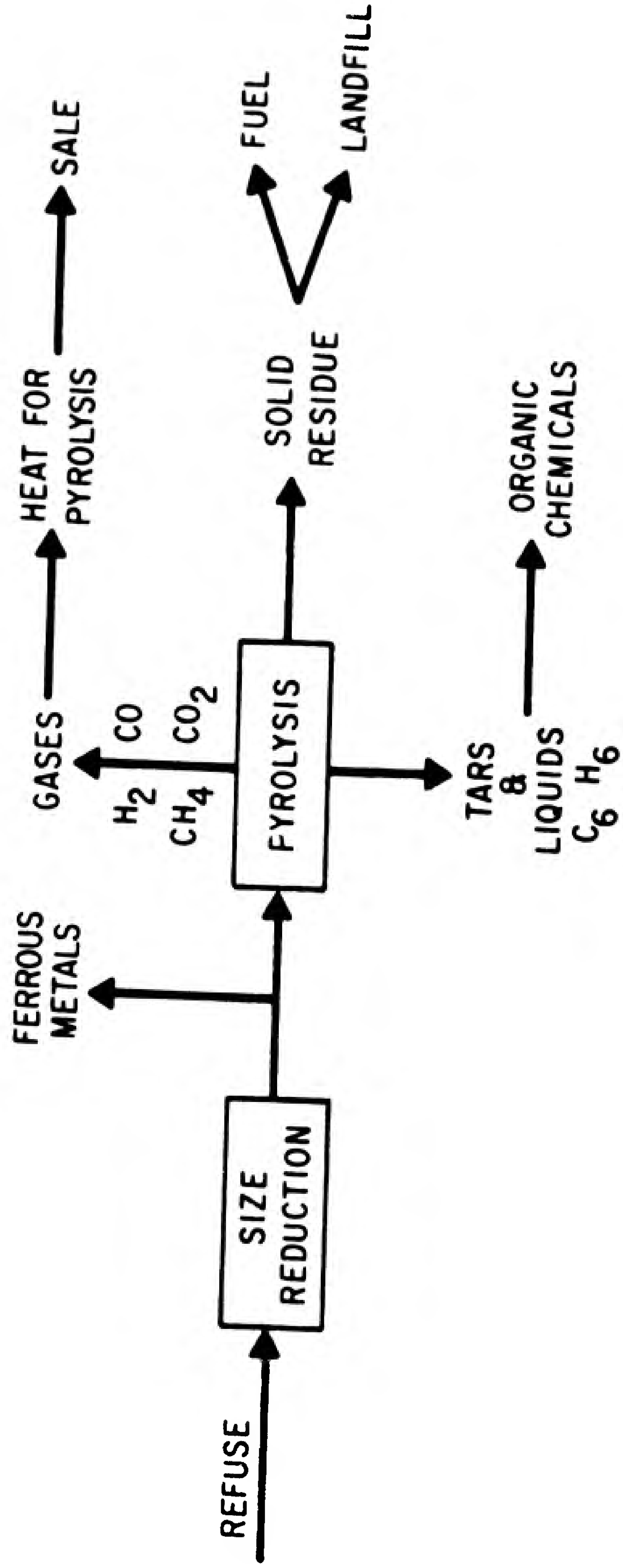

Figure 10. Pyrolysis

refuse, a 93.75 percent reduction in volatiles has been achieved. The smallest practical and economical unit at present is 500 tons/day.

Hercules, Inc. (ref. 4) has received a bid to design, build, and operate a plant to process 500 tons/day of domestic solid wastes. The operation includes: removal of ferrous metals; shredding of the remaining refuse and mixing with sewage sludge to give 50 percent moisture content; the mixture is put in digestors using mechanical mixing and forced air to promote bacterial degradation; the non-digestibles are separated by techniques borrowed from the mining industry and subjected to pyrolysis; the residue undergoes separation by screens and gravity tables. The products from digestion are water, carbon dioxide, and humus. The products from pyrolysis are gases and oils that can be used for fuel or as sources of chemicals. The sand and grit go to a landfill. The glass is finely ground and can be used as road-bed ballast.

The process proposed by the Envirsol Corporation (ref. 40) includes grinding, density separation by air elutriation, pyrolysis of the lighter fraction, additional grinding and various separation, cleaning and extraction techniques for the heavier fraction yielding marketable metals, and pyrolysis products to be used as fuel or source of chemicals to be marketed.

The Waste Distillation Corporation (ref. 38) proposes an operation consisting of shredding, preliminary drying, a three-step pyrolysis process including drying, charring, and gas generation. The gases generated are used to maintain the heat required for pyrolysis with the excess accumulated for fuel or other purposes.

The Bureau of Mines (ref. 41) is studying the conversion of refuse to oil by heating it under pressure with carbon monoxide and steam. They report that more than two barrels of oil are produced per ton of dry, ash-free waste material. This oil has a low sulfur content (near 0.1 percent), which makes it a desirable fuel.

j. Compaction

Compaction as a volume reduction technique is used primarily as a means of decreasing the volume to be transported to the disposal site. Units vary in size from an appliance (ref. 42) serving one household to those that can compact the refuse from an entire community (refs. 43, 44). Compactor-baler units are available in sizes to handle the waste from communities of less than 100,000 up

to 500,000 people (ref. 43). Compacted and baled refuse can be stacked neatly, conserving space and thus increasing the useful life of a sanitary landfill (ref. 43).

In 1969 the following general conclusions were reached by the Solid Waste Management Office (ref. 45) on the much publicized Tezuka Refuse Compression System from Japan. (1) The process can achieve zones of very high compaction inside bales without expensive hydraulics by concentrating the force onto small areas. (2) The overall process appears complicated and cumbersome and can probably be appreciably improved through additional process engineering. The report also questions the claim that the process is capable of producing sterile blocks of refuse which can be used for building blocks. The bales are not sterile, gas production has occurred inside them, and the blocks can be used as building blocks only if enclosed in some load-bearing material.

k. Pulverization

Pulverization or grinding of refuse is a unit process that often precedes another treatment operation, i.e., incineration or pyrolysis. It is also claimed that ground refuse can be deposited directly on the ground without the necessity for daily cover and not be a source of odors or an attractant for insects or rodents (refs. 46, 47). Pulverization tends to homogenize the refuse making it easier to handle (ref. 27). Most grinders on the market are essentially hammer-mills, some with horizontal (ref. 48) and some with vertical rotors (refs. 46, 49).

The Enviro-Chem pyrolysis process, the CPU-400 fluidized bed unit, and the Plaquermine Parrish, La. municipal incinerator all use the Eidal vertical grinder for pretreatment of the refuse (refs. 29, 30, 49, 50).

SECTION III

RESOURCE RECOVERY

By presidential edict (ref. 5) the emphasis of federally sponsored research in the solid waste management area is now on techniques for recycling materials. Solid waste thus becomes a resource rather than a reject. The heterogenous nature of this resource presents the greatest difficulty to its economic development.

Sorting at the point of generation of the refuse resulted in increased collection costs because of the separate collections required (ref. 51). A study in Madison, Wisconsin, showed that approximately 45 percent of the newspapers in the test area were recovered by sorting at the household (ref. 51). Similar separate collection of newspapers is proposed by two Louisville, Kentucky, newspapers (ref. 52). In most cases labor costs prohibit hand-sorting at the receiving station. Magnetic separation of ferrous metals from incinerator residue is practiced in some instances.

Preliminary investigation of an air classification system (ref. 51) (fig. 11) has shown it to be feasible for the sorting of several types of solid waste. The operation, in general terms, is as follows: the ground refuse is introduced into a zig-zag shaped vertical unit with an upward air flow. The particles "are fractionated according to density, size, and aerodynamic properties." A series of these columns with varying air velocities can achieve increasingly finer separation.

In 1969 about 20 percent of the paper produced was recycled (ref. 53). It is estimated that each ton of newsprint that is recycled saves some 17 trees (refs. 52, 53).

Both Reynolds and Alcoa operate aluminum can collection centers (refs. 54, 55). Approximately 30 percent of the aluminum comes from salvage (ref. 56). Members of the Glass Container Manufacturers Institute are opening bottle-redemption centers in 25 states (ref. 57). The bottles will be ground into cullet and used in the manufactur of new glass products (ref. 57). Owens-Illinois opened a plant in Ann Arbor and is paying $0.005 per pound for glass containers. During the first day they obtained 8 tons of glass containers (ref.

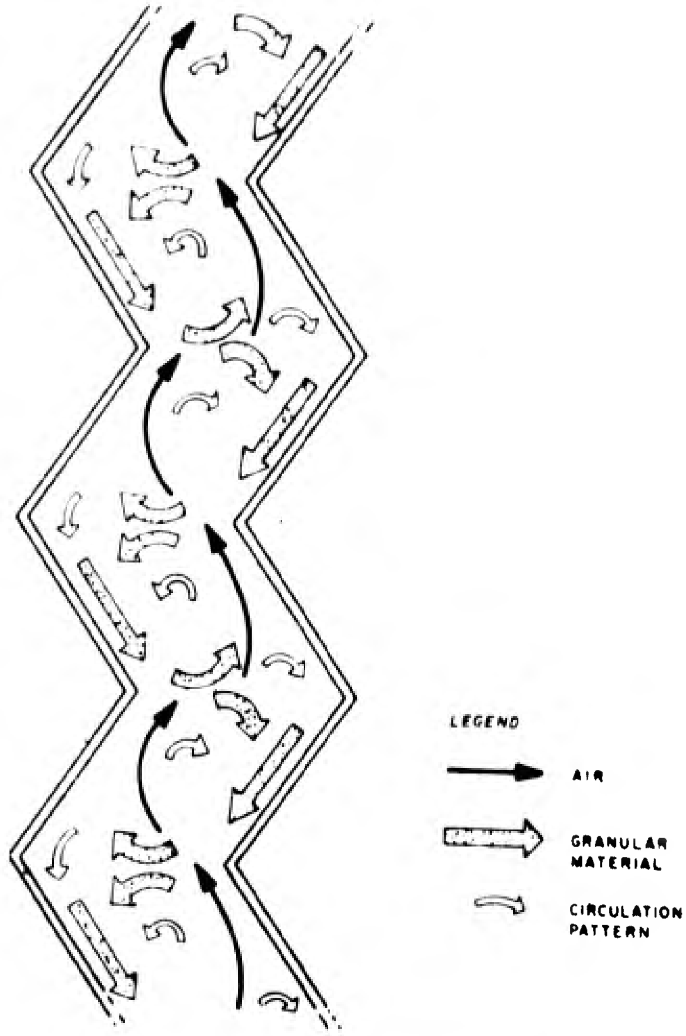

Figure 11. Air Classification

58). Another use for glass is in the manufacture of "glasphalt;" an experimental paving material (ref. 59). The ground glass replaces the gravel and stone used in regular asphalt. The glasphalt consists of 60 percent cullet, 33 percent stone dust, 5 percent asphalt, and a small percentage of lime. A test strip paved with glasphalt is undergoing evaluation.

Automobile tires present a serious disposal problem (ref. 60). When buried in landfills they tend to migrate to the surface as a result of compaction rebound. When burned in incinerators they release large quantities of air pollutants and the high heat release can damage the grates. Pyrolysis of used tires gave the following results: the solid residue had a heating value of

approximately 13,000 BTU/lb; the liquid products contained around 50 percent aromatics, 30 percent paraffins and naphthenes, and 20 percent olefins; the gas generated contained around 50 percent hydrogen and had a heating value of some 850 BTU/cu. ft.

Switching from the convenience of the no-deposit, no-return container to the returnable bottles is in essence resource recovery before the item enters the refuse stream. It also reduces the volume of refuse to be stored, collected, transported, treated, and disposed, all of which costs money. National costs for solid waste management amount to some $4.5 billion/year, and ranks third in public expenditures behind schools and roads (ref. 27).

Composting of municipal refuse has enjoyed on-again off-again popularity. The possibility of profits from refuse is very attractive, and periodically a group of investors finance a new compost plant. Composting of municipal refuse is generally a mechanically assisted, aerobic degradation of the organic material to an inoffensive humus-like substance (ref. 27). In some instances, manures or sewage sludges have been added to increase the moisture content (ref. 27).

The major problems have been the manufacture of an aesthetically acceptable end product and the rapid saturation of the market for compost. The presence of glass fragments of various colors, small bits and pieces of plastic and other nondegradables serve to remind the potential purchaser of the origin of the compost and therefore discourage sales (ref. 27). To be used as a soil conditioner the compost must be supplemented with nitrogen. Raw refuse has a carbon-to-nitrogen ratio of approximately 300:1; a ratio of around 30:1 is necessary for good plant growth (ref. 27).

The production of proteins from the cellulose fraction of solid wastes is the subject of several research projects. A recent report called an economic study of the hydrolysis-fermentation of certain organic solid wastes "encouraging" (ref. 61). Agricultural solid wastes such as sugar cane bagasse show particular promise as a source for protein supplements in human or animal feeds (ref. 61).

SECTION IV

SANITARY LANDFILL

The design and operation of a sanitary landfill is covered in detail in AFM 85-11 (ref. 3) and will not be discussed in this report. New developments in this area are primarily in the equipment field. Several manufacturers make equipment specifically designed for the compact and cover operations in sanitary landfilling (refs. 62 through 67).

A multifunction machine that compacts the refuse and buries it in a trench the machine has excavated is presently undergoing testing (refs. 10, 27). The first model of this machine costs $500,000.00 (ref. 27). Because of its very heavy weight, the machine has a tendency to sink into the ground, and can be used only on level ground (ref. 27).

A machine called the Multi-Mover that combines the function of a dump truck, bulldozer, tractor-carryall unit, and carry-dozer is undergoing "a detailed engineering review with respect to landfill service" (ref. 16).

Another unit, dubbed the Mole (being evaluated in King County, Washington) (ref. 10), is placed in a trench where it receives the refuse, compacts it at 200 psi, and extrudes it into the trench (refs. 10, 27). The refuse is then covered with compacted dirt by a bulldozer (ref. 10).

SECTION V

COSTS

Municipal refuse processing and disposal costs are highly variable. Meaningful information is often lacking because of poor record keeping. Data on new techniques is of necessity sparse because of lack of extensive operating data.

Such information as could be gathered and judged reasonably reliable is presented in table II.

Table II

MUNICIPAL REFUSE PROCESSING AND DISPOSAL COSTS

Process	Capital	Operating	Remarks	Reference
Compaction	$3000/ton (daily capacity)	$2.50-3.50/ton	Municipal size unit	44
Incinerators	$5075-8429/ton (daily design capacity)	$4.48-11.08/ton (waste processed)	Five municipal incinerators 300-600 ton/day	13
Volund Type Incinerator	$6500-7500/ton (daily capacity)	$2.75-5.00/ton*	Minimum size 200 ton/day	12
Consumat (Starved Air)	$74,500 for 1 ton/hr unit (with auto loader)	$1.00/ton*	---	19
Combustall (Starved Air)	$13,150 1000 lbs/hr unit	$0.30/hr ** $2.80/hr	Afterburner only Afterburner and overfire	68
Underground Incineration	---	$3.28/ton	Field test	23
CPU-400 (Fluidized Bed)	---	$4.00/ton	Predicted - Includes recovery from electricity generated	30
Torrax (High Temperature)	$12,500/ton (daily capacity)	$4.40/ton	Without credit for steam; amortization not included	15

Table II (cont'd)

Process	Capital	Operating	Remarks	Reference
Melt-Zit (High Temperature)	---	$8.50/ton	---	26
Enviro-Chem Pyrolysis	$8000/ton (1000 ton/day plant)	$7.40/ton $8.90/ton	Owner operated Monsanto operated	39
Sanitary Landfill	---	$0.70-3.50/ton	National range	69
Sanitary Landfill	---	$1.22-1.50/ton	94,000 ton/yr	62
Sanitary Landfill	---	$2.22/ton	55,000 ton/yr	70
Open Burning Dump	---	$0.30-0.60/ton	---	69
Collection (Automated Vehicle with Mechanical Arm)	- -	$1.60/home/mo $0.70/home/mo	Curb service Alley service	71

*not including financing and amortization

**gas only

SECTION VI

STORAGE, COLLECTION AND TRANSPORT

Storage of municipal refuse at the point of generation is normally the individual's (generator's) responsibility.

The advent of the kraft paper refuse sacks and the plastic bag for home storage is probably the only noteworthy item in this area. Its benefits are time-saving in the collection process and improved sanitation. Home compaction units that reduce the volume at the point of generation thus reducing storage, collection, and transportation requirements are probably too expensive to become a prevalent item (ref. 42).

A one-man collection system operated by the city of Inglewood, California has been found to be very successful (ref. 72). High pay provides an economic incentive to employees, and the results show a 50 percent decrease in the man-hours required per ton collected over an 8-year period and a 65 percent decrease in accidents (ref. 72).

An automated truck with a mechanical arm enables one man to collect refuse from about 4,500 homes per week (ref. 71). Eighty-gallon containers-on-wheels are furnished to each home-owner and are easily placed at the curb on collection day (ref. 71). Alley service using 300-gallon containers (one container per four families) can also be provided with the same vehicle (ref. 71).

A vacuum line collection system that transports the material from the household to a central incinerator is installed in an apartment complex in Sweden (refs. 27, 73). The solid waste is carried in an air stream moving at about 90 feet per second (approximately 61 mph) (ref. 73). The Solid Waste Management Office is investigating the feasibility of a household shredder device that would enable most refuse to be transported in the existing liquid waste pipelines (ref. 26). This would naturally require some modification of present waste-water treatment systems. The cost of these modifications would be offset by savings in collection costs (ref. 26). This is still several years away from an operational model (ref. 26).

A study in Philadelphia has shown pipeline transport of shredded solid wastes mixed with water to be technologically feasible and economically attractive, although many problems remain to be solved (ref. 73). Slurries up to 12 percent by weight of solid waste were pumped with little difficulty (ref. 73).

In an effort to increase the effectiveness and use of collection vehicles, computer programs have been developed to determine the most efficient routing of the vehicles (refs. 74, 75).

A new type of collection vehicle using continuous, rotary screw action rather that a packer blade for compaction is now available (ref. 74). It is claimed that the continuous compaction saves time on collection routes and the lack of hydraulic systems greatly reduces maintenance requirements (ref. 74).

To reduce the time that collection vehicles are out of service because of long trips to and from the disposal site, transfer stations are often employed where distances and/or travel times are excessive. Here collection vehicles, normally 20- to 30-cubic yard capacity, transfer their contents to large trailers that have up to 75-cubic yard capacity. The refuse is usually compacted in the trailer that, when full, makes the trip to the disposal site.

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13. ABSTRACT

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New methods were investigated for processing and disposal of municipal refuse. Volume reduction techniques including incineration and several variations, pyrolysis, compaction, and grinding are discussed in detail. Resource recovery and storage, collection and transportation are also covered. New equipment for sanitary landfill operation and selected cost data conclude the report.

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